Palynology of young acid forest soils in the Netherlands

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Abstract

The organic horizons of acid forest soils are suitable subjects for pollen analysis. The pollen profiles of these soils show a complete registration of the local landscape ecological succession during the last centuries.

The organic profile and a part of the mineral profile of five acid forest soils in various tree plantations in The Netherlands, have been analyzed. The pollen profiles of acid forest soils are clearly zonated.

The pollen spectra extracted from the mineral horizons show a reflection of the former landuse systems. After reafforestation the annual pollen influx is systematically incorporated in the organic horizons, formed on top of the mineral profile. The pollen spectra of the organic horizons show the development of the forests.

The distribution of fungal remains and spores are not zonated through the profiles. There is some evidence that selected types form assemblages, characteristic for various tree plantations.

Introduction

In Post Mediaeval Time humankind completed the construction of the man made landscape in Northwest Europe. Unfortunately, due to the general disruption of the upper part of the soil profile, very few sites are suitable for palynological research of historical time. Buried soils and regenerated peat bogs are important sample sites for the investigation of Post Mediaeval Time. The undisturbed organic profile of young acid forest soils also can be used for this purpose.

In the Low Countries most forests were planted in the struggle against sand drifting. During the 19th century a substantial part of the drift sand areas was afforestated, after the replacement of the plaggen agriculture by other forms of land use. Scotch pine (*Pinus sylvestris*) was the most planted tree. Beside pine plantations, smaller afforestations were realized existing of *Pinus nigra*, spruce (*Picea abies* or *Pseudotsuga*) and oak (*Quercus robur* or *Q. rubra*). The history of most afforestations in The Netherlands has been recorded in landscape management documents and the age of several tree plantations is very well known. The development of the forest vegetation is recorded in pollen content of the organic profile of the forest floor. Therefore the forest soil is an important tool in palynological research of historical time.

In this paper the results of pollen analysis of both mineral and organic horizons are presented. A selection was made of five forest soils in various tree plantations in The Netherlands (Figure 1).

Soil development under pine trees

The investigated acid forest soils are classified as cambic arenosols (FAO/Unesco, 1988), also called micropodzols. This soil type forms a first phase in the development from an initial soil to a spodosol.

The soil ecological development on drift sand deposits in the 'Hulshorsterzand' area is described by Emmer et al. (1991). This description is representative for the global development on chemically poor sandy deposits in The Netherlands. The observed succession of phases in soil formation is summarized in Figure 2.

Evidently soil formation and vegetation succession are close correlated processes. During the first phase the

Figure 1
Location of the sample sites. The Hoornse Bos site is a Pinus nigra plantation on the isle of Terschelling. Sites Nabbegat and Rakt form part of oak plantations and Weerter Bergen 1 and 2 of Pinus sylvestris *plantations.*

drifting sand (C-horizon) will be fixated by algae, lichen, sand hair-moss and grey hair-grass (*Corynephorus Canescens*). These pioneers add carbon and nitrogen to the chemically poor soil by the deposition of a surfacial litter (L-horizon) and subsurfacial roots (initial A-horizon).

During the second phase seeds of pine trees can germinate and grey hair-grass is replaced by sheep's fescue (*Festuca ovina*). A light grey coloured albic E-horizon will become visible under the litter horizon after 5 to 10 years soil development. This process is caused by leaching of iron and aluminium in acid soil conditions. The third phase results in the development of the fermentation (F) horizon after 40 to 80 years. The F-horizon exists of fragmentated organic litter. The tissue structure of the organic material in the F-horizon is still visible. When this organic horizon extends to a thickness of about 2 cm, *Festuca ovina* (rooting in the mineral soil) is replaced by *Deschampsia flexuosa*, which is rooting in the organic horizons. During the third phase a differentiation will become visible between the less decomposed material of the F1-horizon and more decomposed organic material of the F2-horizon.
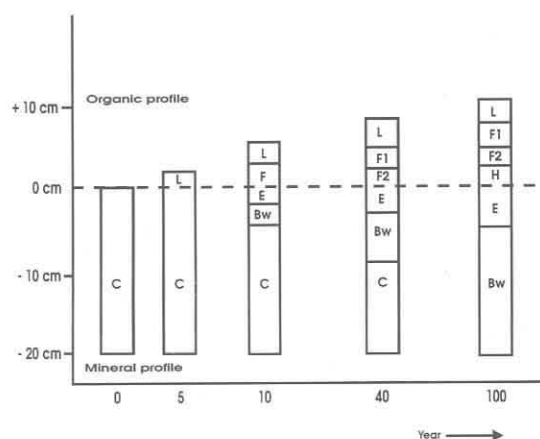
The increasing brown colour below the mineral E-horizon points to an alteration (Bw) horizon. The development of a Bw-horizon starts already in the first phase. Homogenisation of the sedimentary structures, in situ weathering of the mineral grains and some precipitation of iron are the main processes. The Bw-horizon cannot before the afforestation, be clearly distinguished until the third phase. In the fourth phase the humic (H) horizon is developed, consisting of strongly fragmentated and decomposed organic matter, without recognizable tissue structures. This H-horizon completes the development of the organic horizon (Figure 3). Among the vegetation of the forest floor species of the climax phase appear, like blueberry (*Vaccinium myrtillus*).

The main differences between a spontaneous forest development and plantations on drift sand can be briefly summarized:

1. The forest development of plantations starts in the second phase of the described spontaneous succession.
2. The mineral soil of plantations may contain pollen assemblages of former vegetation types, incorporated before the afforestation.

Figure 2
The succession of the phases in forest soil develop-ment. A complete organic profile develops after 100 years. The following organic horizons can be recognized: surfacial litter horizon (L), fermentation horizon (F1 and F2) and a humic horizon (H). Beneath the organic profile, a mineral profile develops in drift sand (C horizon), containing two horizons: the eluviation horizon (E) and the alteration horizon (Bw).

Figure 3
Profile, showing the organic and mineral horizons of 'micropodzol' in a 100 years old pine plantation in the 'Weerter Bergen'.

Pollen profiles of acid forest soils

In this paper five pollendiagrams of acid forest soils will be discussed. The five sample sites (Figure 1) have been chosen in various tree plantations.

Two sites are situated in an inland dune landscape, partly planted with *Pinus sylvestris* (Weerter Bergen 1 and 2). Site Hoornse Bos is located in a *Pinus nigra* plantation, which forms part of a coastal dune landscape. Site Nabbegat is in a *Quercus robur* forest and Rakt in a plantation of *Quercus rubra*. The oak-sites are plaggen soils overblown by drift sand.

The samples were taken from the upper 150 mm of the forest soils, including the organic profile and the top of the mineral soil. In a small excavation the profile was divided into 10 slabs of 15 mm each (except profile WB1). From every slab a subsample was taken for pollen analysis. Pollen extractions were prepared by applicating the acetolyses method (Fægri & Iversen, 1975). *Lycopodium* spores were added to be able to estimate pollen concentrations (Stockmarr, 1971).

The pollen diagrams (Figures 4-8) show the sequence of soil horizons, the pollen concentration curve and the main pollen curves. The relative pollen scores are based on the total pollen sum (100 %).

Young forest soils in pine plantations

In the bronze age the natural Holocene deciduous forests in the surroundings of Weert were already partly degradated into heaths and local sand driftings, due to shifting cultivation. Later, the use of the heath for plaggen digging accelerated the degradation, resulting in extensive drift sand areas and the development of inland dunes (Van Mourik, 1988).

The active drift sand area 'Weerter Bergen' reached its maximum size around 1700 AD. During the second part of the 19th century the plaggen agriculture system was replaced by more modern forms of landuse. The 'Weerter Bergen' area was stabilized by reafforestation with pine trees, which could survive in this kind of environment and provided useful wood for the coal mines.

On the Weerter Bergen 1 site (WB1) the land degradation did not result in serious sand drifting. The organic horizon (F) of WB1 (Figure 4) formed directly on a paleosol, classified as buried carbic podzol. The carbic podzol is the result of degradation of a preceding cambic podzol. The latter can be associated with the soil development in deciduous forests. There is no genetic relation between the paleosol and the organic horizon; The soil profile can be described as polycyclic.

The Weerter Bergen 2 profile (WB2, Figure 5) is located in a Scots' pine plantation where the preceding carbic podzol (2EA) is buried by a thin layer of drift sand. This suggests active sand drifting in the surroundings, before reafforestation. The polycyclic character of the profile is clearly expressed by the drift sand deposit.

The characteristics of the pollendiagrams WB1 and WB2 (Figure 4 and 5) are similar. The pollen content of both 2EA horizons reflects the former heath vegetation. The pollen assemblages of WB1 and WB2 agree with the pollen assemblages found in adjacent polycyclic podzols (Van Mourik, 1988). In older parts of these podzols, the occurrence of somewhat high percentages of Tilia, like in WB2, is also observed. Havinga (1984) explained the higher percentages of Tilia pollen by selective corrosion processes.

On both locations the heath was reclaimed in 1948 and planted with *Pinus sylvestris*. Simultaneously the development of an organic profile started and the incorporation of pollen in the organic horizons. This explains the quick increase of *Pinus* pollen percentages. Figure 4 shows that the pine forest is proceeded by a stage with Gramineae. This agrees with the observed vegetation succession of a drift sand area in the Veluwe (Fanta, 1986), where the initial tree-less stage is dominated by grasses. The dominance of *Pinus* pollen in the organic horizons of the profiles WB1 and WB2 is according to a homogeneous pine forest due to reafforestation. The spectra near the top of the profiles show a slight decrease of *Pinus* in favour of Gramineae. This is probably the effect of acid rain, which is rich in nitrogen. The relative youth of the plantations is reflected in the composition of the organic profile, showing only an undifferentiated F-horizon and lower pollen concentrations. The pollenconcentration in the F-horizons increase from top to bottom. This can be explained by concentration of pollen grains in the organic sediment due to selective decomposition of organic material during time. The pollen concentration curves of the mineral horizons reflect the pollen infiltration. The pollengrains in this part of the mineral soil are mainly incorporated in organic excrements (Van Mourik et al., 1988). The distribution of pollen is explained by the differences of soil fauna activity.

The Hoornse Bos profile (HB, Figure 6) is situated in a *Pinus nigra* plantation that forms part of the coastal dune area on the isle of Terschelling.

The coastal dunes supplied the inhabitants with fuel, organic dung and cattle fodder. The intensive use of this area destroyed the vegetation, that protected the sandy soil against wind erosion. During a storm, in 1863, the heath north of the village Hoorn was covered by drift sand. From 1885 on the Government passed on to a rapid plantation of bent-grass and the dunes became fixed. In 1909 'Staatsbosbeheer' started reafforestation.

The Hoornse Bos site (1923) reflects this history well. The pollen association of the bottom sample is characterized by a high proportion of Gramineae, probably bent-grass. After the plantation of *Pinus nigra*, an organic profile (F-and L-horizon) developed and *Pinus* increased in dominance until the top of the litter layer. The pollen concentration curve shows pollen infiltration

to a depth of 105 mm. The dune sand has been deposited almost sterile. It is remarkable that the maximum pollen concentrations are found in the L-horizon and not in the F-horizon. This suggests that concentration by ageing and decomposition do not take place, perhaps caused by unfavourable soil conditions.

Young forest soils in oak plantations

Before the introduction of fertilizers, organic material obtained from forests and heath was used as dung. The introduction of organic dung and the development of the so-called plaggen soils has not been satisfactory dated. Fractionated radiocarbon dating suggests that the development of some plaggen soils started before 600 AD (Van Mourik et al., 1988).

The increasing removal of organic matter, due to the extending of arable land, led to serious soil degradation and sand drifting. Not only parts of forests and heath disappeared, but also cultivated areas were buried by drift sand deposits. The plaggen soils of Nabbegat and Rakt were overblown by drift sand between 1838 and 1866 (Van Mourik & Ligtendag, 1988; Van Mourik, 1987).

Unlike the WB1 and WB2 sites, the overblown plaggen soils of Nabbegat and Rakt have been planted with respectively *Quercus robur* and *Quercus rubra*. After stabilization, soil development started in the drift sand deposits, resulting in initial podzolic soils (E and EC, Figure 7 and 8).

The pollen content of the plaggen soil and overlaying drift sand deposit of the Rakt profile has been described by Van Mourik (1987), the Nabbegat profile by Van Mourik & Ligtendag (1988).

The lower spectra of the Nabbegat and Rakt profiles (Figure 7 and 8) show the influence of pollen, transported from cultivated areas in the surroundings (e.g. Cerealia and Gramineae). Also Ericaceae pollen show the existence of a former plaggen soil in the neighbourhood, because heath was used as organic dung.

The pollen concentration curve of Rakt profile (Figure 8) shows a top to bottom decrease in the mineral horizons. This can be explained by the pollen infiltration processes during the stabilization of the surface of the drift sand deposits.

The spectra near the boundary of the mineral soil and the organic profile are characterized by decreasing percentages of Cerealia and Ericaceae and an increase of Gramineae, characteristic for a short tree-less period (Fanta, 1986).
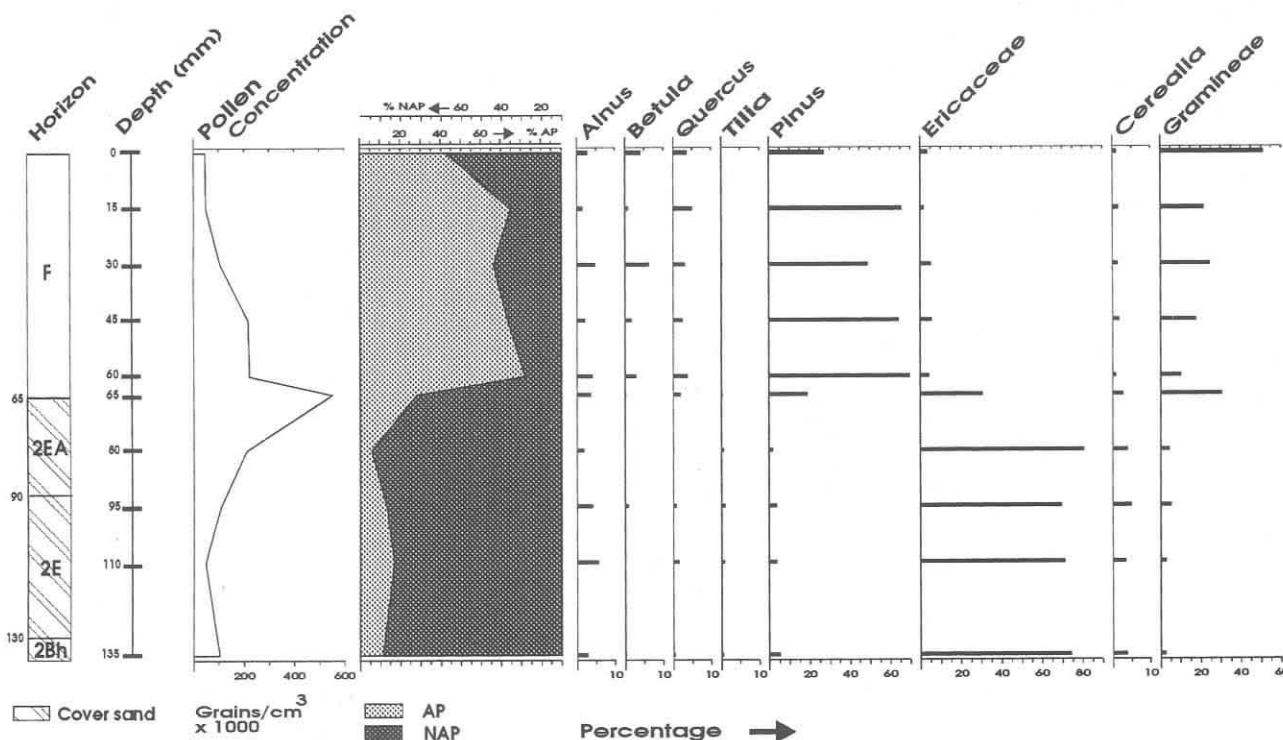
Pollen diagram Weerter Bergen 1 (WB1)

Figure 4
Pollen diagram Weerter Bergen 1 (WB1).For explanation of the horizon symbols: see Figure 2.

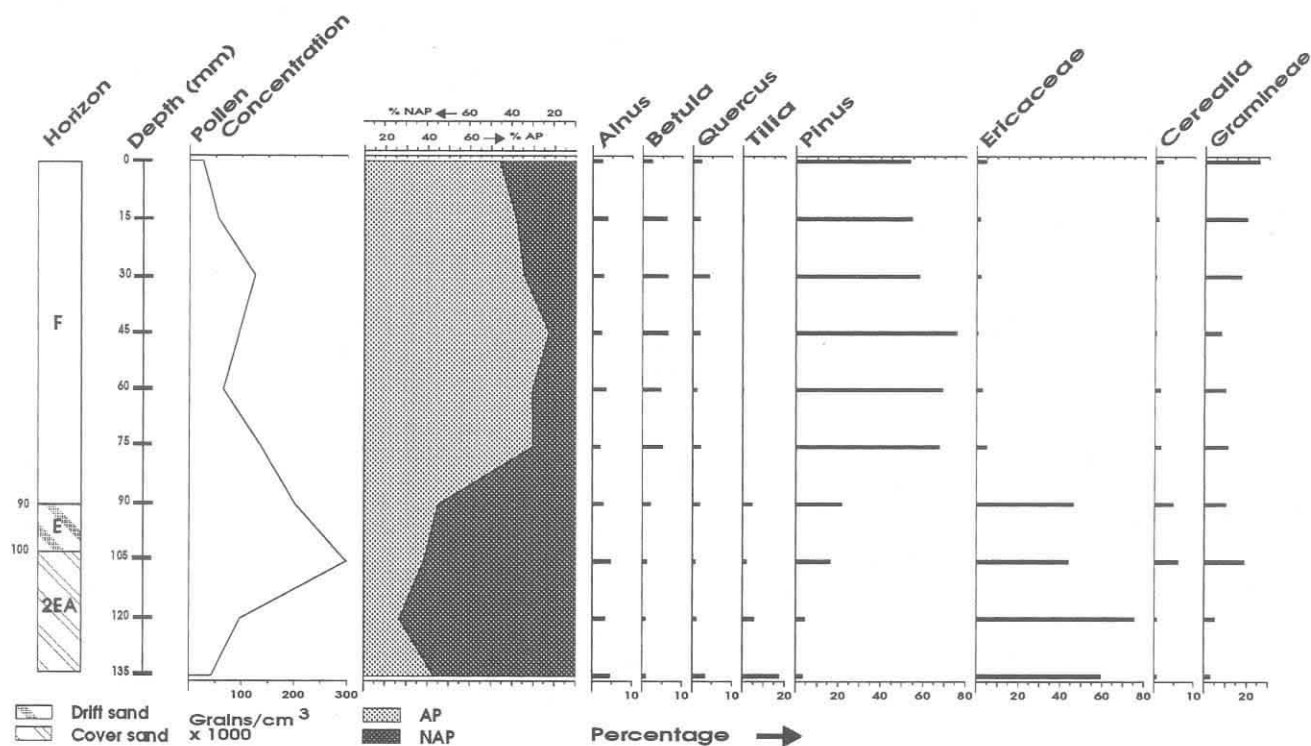## Pollen diagram Weerter Bergen 2 (WB2)

Pollen diagram Weerter Bergen 2 (WB2).For explanation of the horizon symbols: see Figure 2.
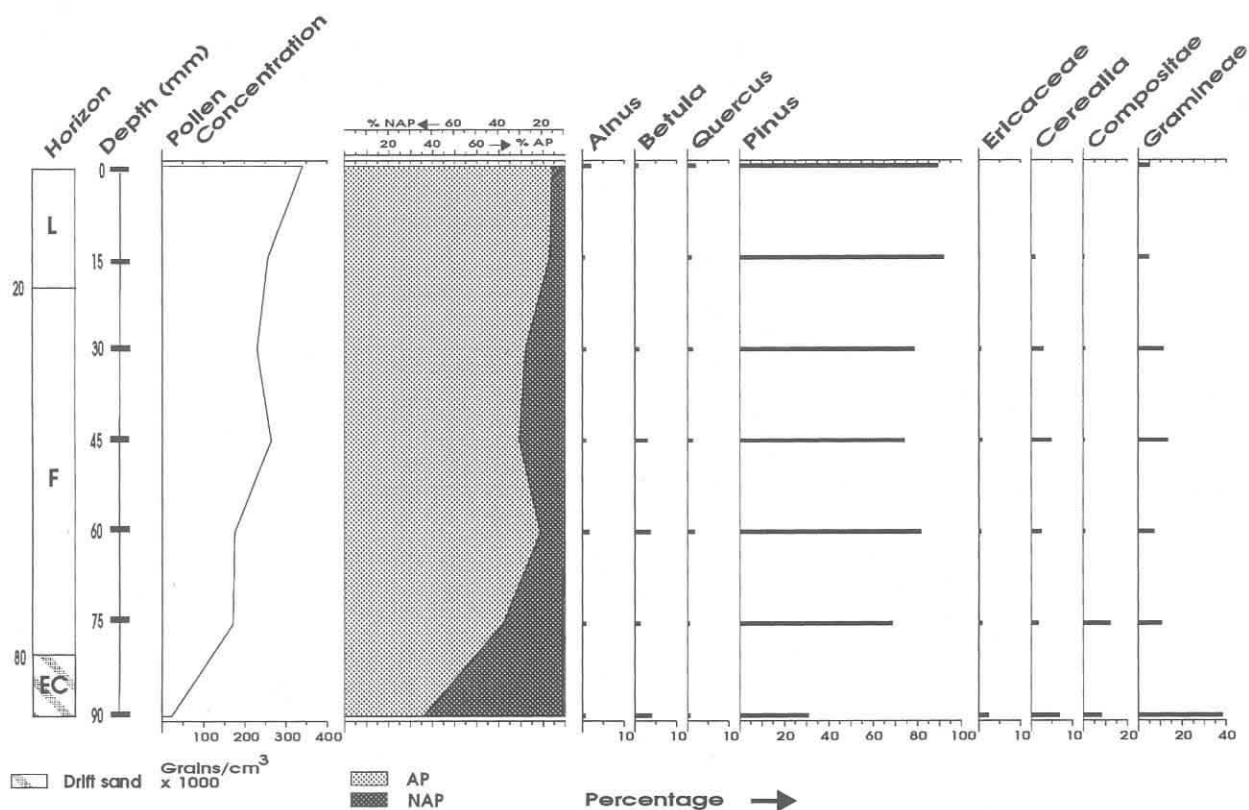
Pollen diagram Hoornse Bos (HB)

Pollen diagram Hoornse Bos (HB). For explanation of the horizon symbols: see Figure 2.
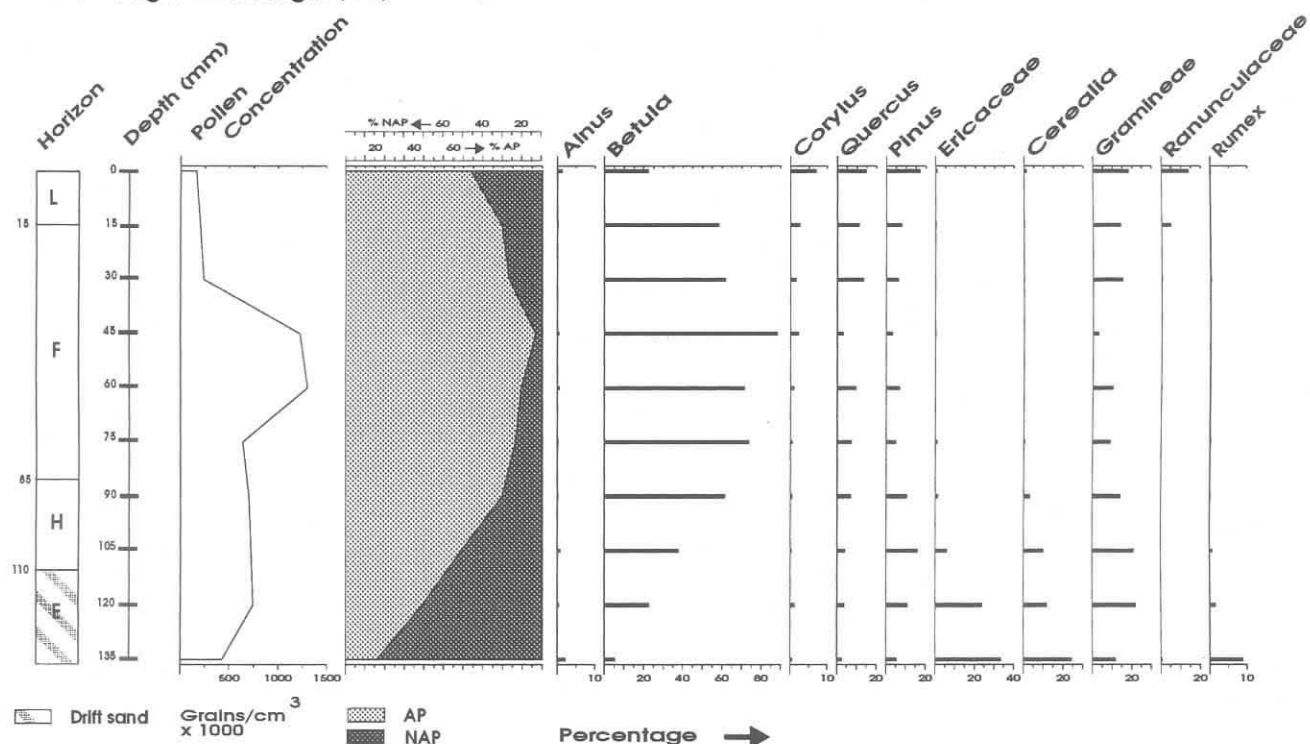
Pollen diagram Nabbegat (NG)

Figure 7
Pollen diagram Nabbegat (NG).
For explanation of the horizon symbols: see Figure 2.
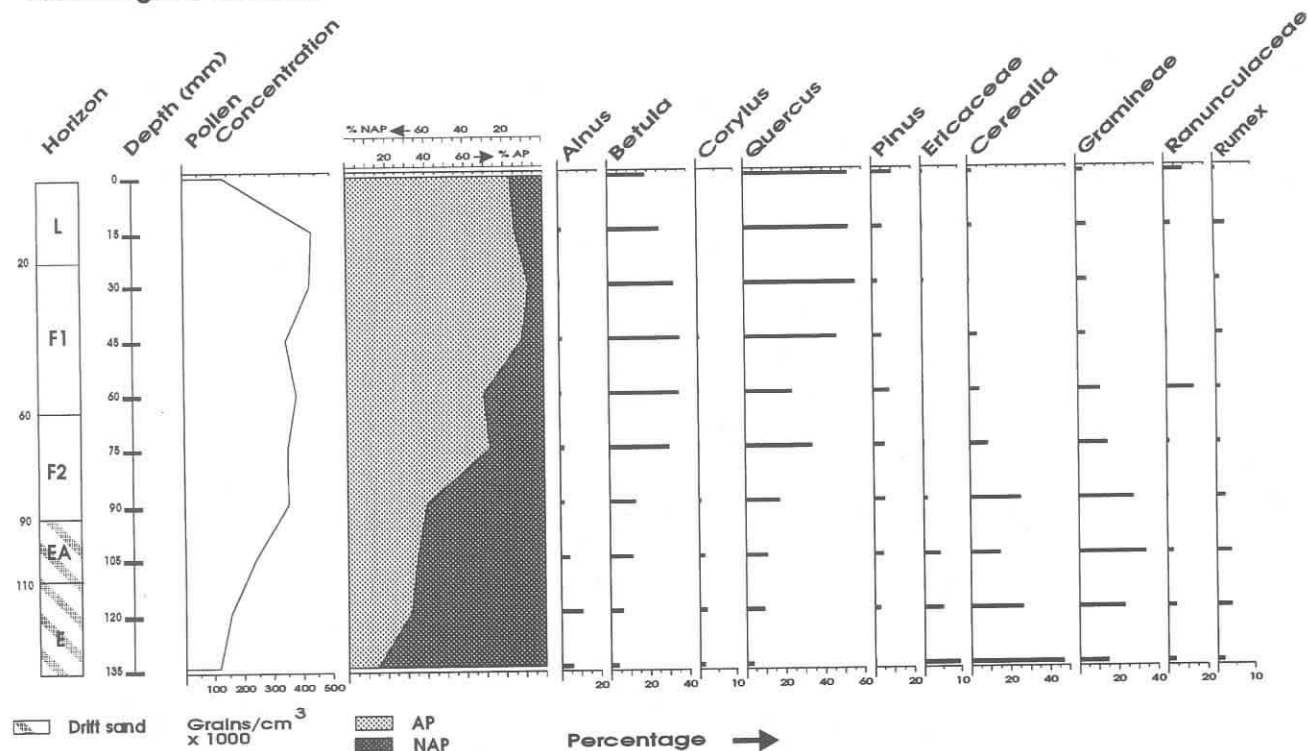
Pollen diagram Rakt (RKT)

Figure 8
Pollen diagram Rakt (RKT).For explanation of the horizon symbols: see Figure 2.

Although both profiles are in oak plantations, the spectra of the organic horizons show first an increase of *Betula* pollen, followed by *Quercus* (Q. *robur* in Rakt; Q. *rubra* in Nabbegat). During the first stages of the oak forest, birch trees develop spontaneously. When the forest is fully grown, birch trees are suppressed by oak. The Rakt profile shows this phenomenon. The Nabbegat profile also shows a decline of the percentage of *Betula* pollen, but the forest of Nabbegat is more heterogeneous.

The actual vegetation of the forest floor of Nabbegat is dominated by grasses (*Deschampsia flexuosa*) and ferns (*Dryopteris*). A herb layer is missing on the Rakt location, caused by the more acid conditions of the soil profile. This might be the explanation for the low pollenconcentrations of the organic horizons of the Rakt profile.

Analysis of fungal remains

Microorganisms, mainly fungi, play an important role in the decomposition processes of soils. They decompose organic matter to anorganic components (e.g. CO_2 and H_2O) and humus. The continuous chemical and physical alteration of fresh litter to humus implies a succession of specialized fungi (Gisi et al., 1990). Whereas some fungi can be found on overground parts of plants, most fungi decompose dead organic matter in the organic horizons, where temperature and moisture are more favourable. Soil fungi are mainly responsible for the decomposition of cellulose, lignin and chitin.

Typen	HB	WB1	WB2	NG	RKT
T10	●	●	●	●	·
Type 55A&B*	·	·	●	●	·
T7a,b&c	·	·	·	●	·
T27		·	●	·	·
T14	●	●	●	●	
T45	·	●	●		
T24	·	·	●		
T71	·	·			·
T20a&b	●			●	●
T104	●			●	·
T18				●	●
T118				·	●
T111				·	·
T112				●	
Gelasinospora*				●	·

* After Van Geel, 1976
· Rare
● Abundant

Table 1
Dominant types of the profiles.

Fungi occur in soils as mycelium, spores (conidia) or chlamidospores. The latter two stages are considered as dormant survival structures. The mycelium represents an active stage during decomposition. Soil fungi comprise usually ascomycetes and deutromycetes (Fungi Imperfecti). Most of these fungi are saprophytes (soil-born fungi), the minority is parasitic or semiparasitic on plant roots. Another important group of saprophytic fungi are the basidiomycetes. These fungi live with their mycelia in the soil; They are difficult to isolate (Gams et al., 1987). In the five profiles, spores and other remains of fungi with a characteristic form, were identified as types. Hyphae and other fungal remains with an uncharacteristic morphology, like mycelium fragments, have been excluded. The most dominant types, found in the profiles, are shown in table 1. The photographs with description of the types are presented in plate 1 and 2.

It appeared very difficult to identify the fungal remains and spores. In the first place this method is not adequate to study both the living and the dormant structures of fungi. Mainly the resistant fragments of fungi are saved in microscopic slides, like the thick walled spores of some Fungi Imperfecti. The living structures, or mycelia, have an uncharacteristic morphology and are not recorded. Secondly the grow media, which fungi live on, are destroyed by the acetolysis method. It seemed valuable to group the types in particular assemblages, which are characteristic for local conditions of the environment (Moore et al., 1991). Some types, like T24, T27 and T45 only occur in pine forests (table 1), whereas T18, T18a and T104 are examples for types, living in deciduous forests.

In contrast to the pollen assemblages, the distribution of fungal remains is not clearly related to zones. As the decomposition of organic matter mainly occurs in the organic profile, most associations were found there. A distinction of types within the L-, F- or H-horizon was not visible, probably because of recording only the survival structures and not the decomposing stages of fungi.

Conclusions

Pollen profiles of the acid forest soils show a complete registration of the local landscape ecological succession during the last centuries. Although the five investigated locations have different parent material and paleo pedological characteristics, all pollen assemblages of the mineral horizons (except location Hoornse Bos) contain high percentages of Ericaceae and Cerealia pollen. This reflects the transport of pollen from nearby cultivated areas and heath lands to the locations.

Before reafforestation the drift sand is fixated by algae and grasses. This period is the first phase in soil development. In most profiles, this phase is reflected by the decline of the percentages Ericaceae and Cerealia, proceed by higher percentages of Gramineae pollen.

The drift sand area Weerter Bergen has been reafforestated with pine trees. This causes high percentages of pine pollen in the organic profiles, indicating monocultures. The pollen assemblages of the organic profiles of Nabbegat and Rakt show a more heterogeneous forest. After the plantation of oak trees, first the percentage of birch pollen increase. Oak trees, which grow slower, will suppress birch trees later in succession.

The assemblages of fungal remains show a distinction in environmental conditions. A difference between the assemblages of fungal remains in pine and oak forest is observed. A distinction between the assemblages of fungal remains in L-, F- and H-horizons cannot be made. An important reason for the absence of zonation is the uncharacteristic morphology of the decomposing structures.

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Plate 1

1

T7a - Fruitbody composed of rectangular cells radiating from the middle. Cells have equal measurements (3-5 µm), only around the ostiole the cells become smaller. Ostiole is darkbrown, ostiole collar is 6 µm. The total diameter of the fruitbody differs much. The fruitbody is surrounded by a thin wall (< 1µ).

2

T7b - Fruitbody composed of rectangular cells radiating from the middle. Cells are biggest near the margin, 3-5 µm, around the ostiole the cells become smaller. The ostiole is dark brown and composed of cells with a thicker wall. The diameter of the ostiole collar is 14 µm. The total diameter of the fruitbody differs (irregular pattern) much and the fruitbody has no margin wall.

3

T7c - Fruitbody composed of meandering to radially arranged hyphae with a irregular margin without wall. Ostiole is composed of dark coloured hyphae. Ostiole diameter is 9-10 µm. The diameter of the fruitbody differs much, normally the fruitbody is broken.
T7a, b and c are often found on the epidermis of pine needles. General in all profiles.

4

T10 - Spore(?), globose, brown with a thin wall, 9-10 µm in diameter. Around a hyaline centre concentric, darker and lighter rings are visible. General in pine and oak forests.

5

T27 - (resemble Type 87a and b; Van Geel, 1976).
Ascospores(?), one-celled or one-septate (very rare 2-septate), sometimes with no septum or vague septum. The colour is brown with a coarse surface (scabrate) and a rather thick wall. Sometimes the spores show a single pore or are flattened at one side. Size of spores is rather variable: 28-40 * 15-20 µm.
This type of spore is abundant in *Pinus sylvestris* forest WB2, present in WB1 and absent in profile Terschelling, which is a *Pinus nigra* forest. Also in profiles NG and RKT, T27 appears a few times in the top of the organic profile together with the pine pollen in these profiles.

6

T14 - (resemble Type 6; Van Geel, 1976).
Ascospores (?) one-celled, brown, bilaterally flattened, sometimes with a germ slit along one side. Size: 13 * 6 * 3 µm. General and abundant for all profiles except profile RKT.

7

T45 - germing septate hyphae (cauliflower) widening to 19-24 µm at the distal end.
This type of spores were only found in the litter layer of pine forests. Abundant in the profiles WB1 and WB2 and rare in the profile Terschelling.

8

T24 - Spore(?), elongate, light brown, normally 6-septate and slightly constricted at the septa. Top-cell is larger and rounder than bottom-cell, which is slightly tapering to the end. The wall and the septa are equal in thickness. This type contains a smaller psilate one with a non-septate hyphae asymmetrical at the top cell (24 * 8 µm) and a larger one with a scabrate wall (33-40 * 10 µm).
This type of spores were only found in the litter layer of pine forests. Abundant in the profile WB2 and rare in the profiles HB and WB1.
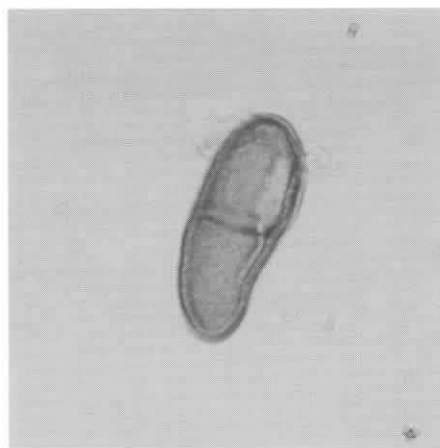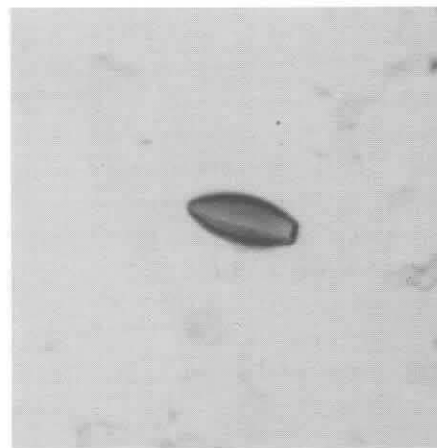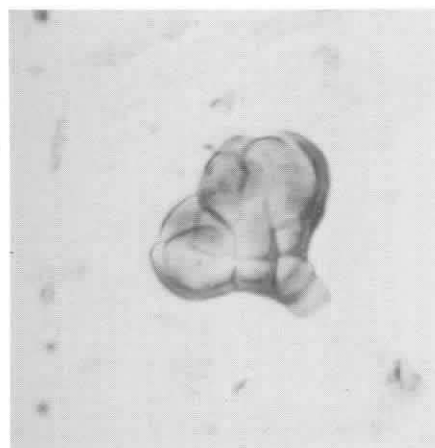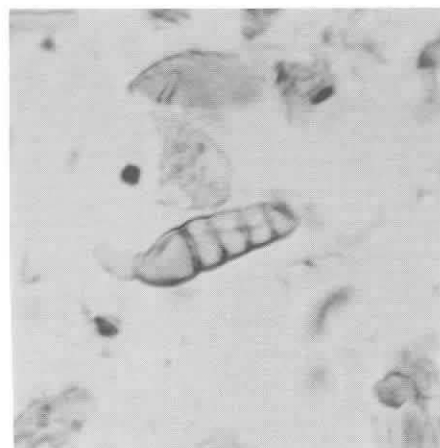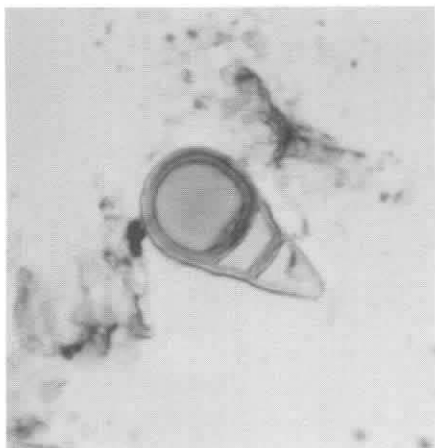
1

2

3

4

5

6

Bar is 10 μm

7

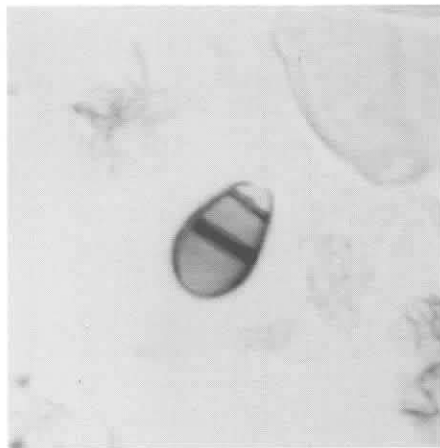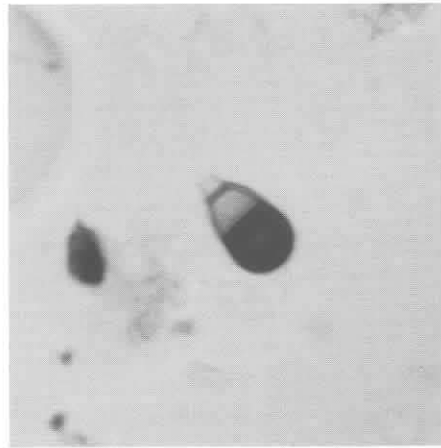
8

Plate 2
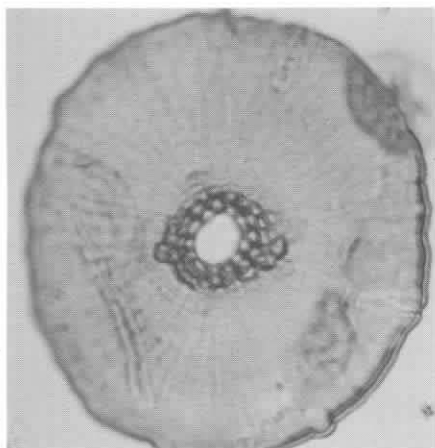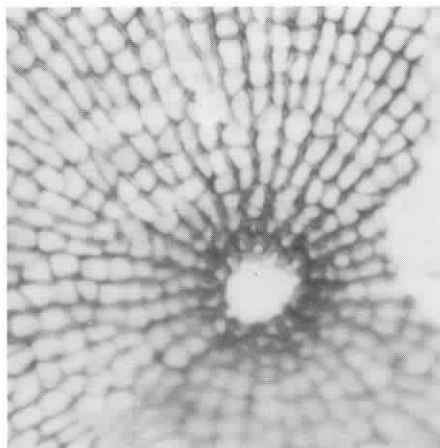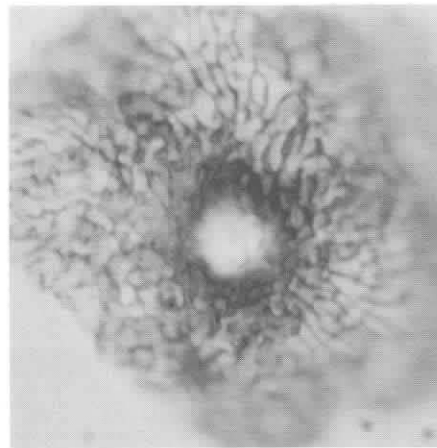
1

T71 - Conidia or chlamidospores(?), top cell is dark brown and round mostly 2-(3)-septate thick walled (2μm), the basal cell has a thinner wall, sometimes hyaline hyphae-like end, corresponding to the place of mycelial attachment. A small pore is sometimes visible in the septa. Size: 24 * 13 μm.

2

T20a - (resemble Type 10 or 11; Van Geel, 1976). Conidia or chlamidospores (?), mostly 2-septate, brown and resembles T20b. T20a is not constricted at the septa. The top cell and the intermediate cell are both the same colour, the basal cell is hyaline and not always present.

3

T20b - (resemble type 10 or 11; Van Geel, 1976). Conidia or chlamidospores(?), mostly 2-septate, sometimes 1-septate, slightly constricted at the septa. 14 μm long and 9-10 μm wide. Top-cell is almost black, basal-cell hyaline, with a truncated end corresponding to the place of mycelial attachment.

4

T18 - Fungal remain, elongate, one-celled, light brown with a thin wall, tapering to the side with an inside folded wall. Size: 26-30 * 10 μm. General for the oak profiles NG and RKT.

5

T118 - Fungal remain, bean shaped, smooth thin wall, a-symmetrical septum (part of hyphae?). Normally one pore (5 μm), sometimes two pores at both ends (due to corrosion?), no annulus around pores. Size: 70-80 * 14 μm. Sometimes one end ending in a non-septated hyphae. General for the oak profiles NG and RKT.

6

T111 - (resemble Type 3; Van Geel, 1976). Ascospore(?) round to ellipsoidal, 19 * 22 μm, muriform with many transverse and longitudinal septa and a thin wall. The colour is brown. This type of spores were only found in the litter layer of mixed oak-birch forests (Rakt and Nabbegat).

7

T104 - Fungal remain, nearly circular in outline, 18 μxm in diameter, made up of radiating files of brown cells with 1 μm thick cellwall. Cells have a curved outerwall (5 μm wide) and are tapering towards a dark ring in the centre. Sometimes a part of a hyphae is visible.

8

T112 - Elongated, one-celled spore, 10 * 26 μm. Spore wall becomes thinner at both ends forming a pore (1 μm or larger due to corrosion). Spore surface can be psilate or scabrate.
This type only appears in the mineral horizons of the profile NG.
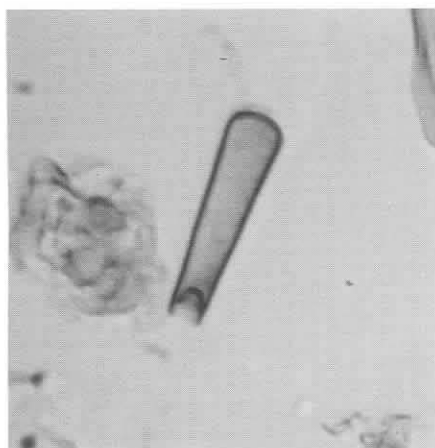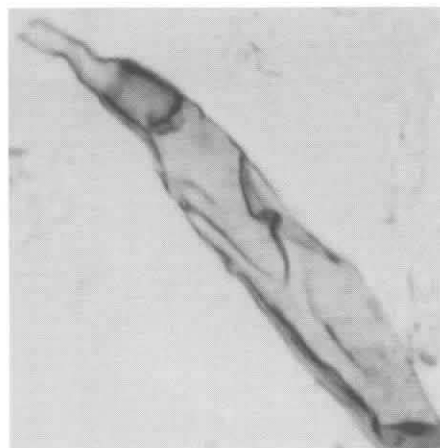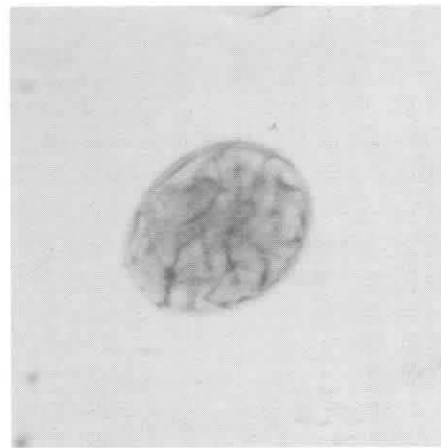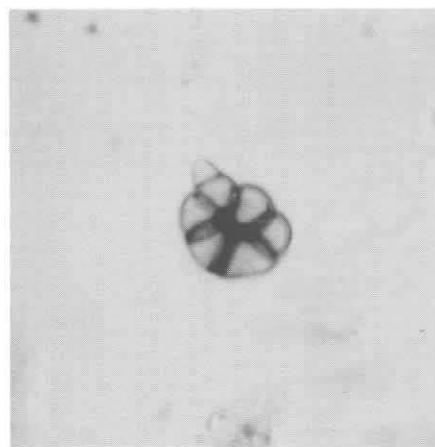
1

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Bar is 10 μm

7

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